Load.	Extensometer.	Difference per half-ton.	Set.
3	424	—	—
$3\frac{1}{2}$	468 to 470	44 to 46	—
4	528 to 540.	58 to 70	—
0	249	—	49
4	545 to 550	—	—
$4\frac{1}{2}$	670	—	—
	715 after half a minute.		
	758 after two minutes.		
	785 after nine minutes.		
0	447	—	247
$4\frac{1}{2}$	798	—	—
5	1200 running slowly off the scale.		

The mean extension from 0 to $2\frac{1}{2}$ tons is 73·6 per ton, which makes $E = 13740$ tons per square inch.

II. "The Electrical Measurement of Starlight. Observations made at the Observatory of Daramona House, co. Westmeath, in April, 1895. Preliminary Report." By G. M. MINCHIN, M.A. Communicated by Professor FITZGERALD, F.R.S. Received April 29, 1895.

The method employed in these experiments for measuring the intensity of the light which reaches the earth from the stars and planets consists in the determination of the electromotive force generated by such light in certain photo-electric cells, the square of this electromotive force being proportional to the energy of the incident light.

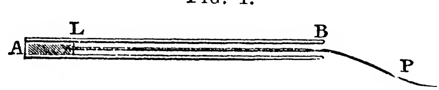
It will, then, be well to describe first the nature and construction of these cells.

The Photo-electric Cells.

In these cells the surface on which the incident light is received is formed by depositing a thin layer of selenium on a surface of clean aluminium, and immersing the sensitive layer in a glass cell filled with œnanthol.

The mode of formation of the sensitive surface is as follows:—

FIG. 1.



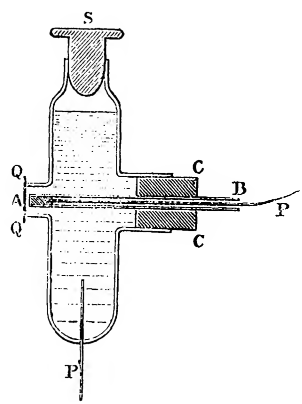
Take a tube, AB, of soft glass, the diameter of the bore of which is 1 mm., or smaller if desired; take a short length, AL, of aluminium wire, which nearly fits the tube, and to one end, L, of this piece of aluminium attach a platinum wire, LP, which emerges from the end, B, of the glass tube, the contact at L being made by boring a fine hole through the aluminium and pinching the two metals together; then, in the flame of a Bunsen burner or a blow-pipe, melt the glass well round the aluminium, until the glass fits round the aluminium as tightly as possible. The contact of the glass and the aluminium should be perfect, or, at least, liquid-tight, and, unfortunately, it has been found hitherto impossible to realise this condition. If this condition could be attained, the photo-electric cells would remain constant in their action for a very long time, if not, indeed, permanently. At present, owing to this want of liquid-tightness, about four weeks seems to be the limit of constancy. (There is also another condition essential to constancy, which will be presently mentioned.)

The next step is to grind the end A of the tube on fine sand or emery-paper until a flat surface is formed by the end of the aluminium wire and the wall of the glass tube, the end of the aluminium wire being then scraped clean.

Now place the tube AB, with the end A uppermost, between two nearly vertical plates of asbestos, the end A just appearing beyond the edges of the plates of asbestos; on the middle of the aluminium wire at A place a very small piece of selenium (about the size of a very small pin-head); heat the asbestos by means of a spirit lamp or a Bunsen flame until the selenium melts on the end A of the tube. Care must be taken to keep the flame away from the selenium, so that the latter melts in virtue of the heat of the aluminium wire. The selenium now lies as a very black little liquid globule on the end of the tube, and it must be spread uniformly over the end of the tube by means of a heated glass rod. The layer of selenium should not be a thick one. The flame being removed, allow the selenium to cool into a hard black layer. When it reaches this condition, apply the heat again, as before, until the black surface changes into one with a uniform brownish-grey colour, the heat being continued after this with great care until the selenium is on the point of melting again into a black liquid. On the first sign of this latter change, instantly remove the heat and blow over the surface of the selenium. This will at once stop the tendency to melt, and the surface will then be in its most sensitive state. There should be no glossy streaks on the surface; if there are, it must be heated over again and the whole process repeated. Screen the tube from light and allow it to cool for a few minutes; it will then be ready to put into the cell with œnanthol.

The œnanthol cell is a small glass tube, represented in fig. 2. It consists of a glass tube about 3 cm. long, and nearly a centimetre in diameter, with two short glass tubes fitted into it on opposite sides; one of these is ground flat, and has a thin quartz window, QQ, cemented to it with gelatine and acetic acid, or glue and glycerine, or any cement that will withstand the action of œnanthol; the other is tightly closed by a cork, CC, through which passes the glass tube, AB, which contains the aluminium and platinum wires above

Fig. 2.



described. The cell is closed at one end by a ground glass stopper, S, and through the other end passes a platinum wire, P′, sealed in. The two poles of the cell are the platinum wires P and P′.

The light of a star is destined to shine through the quartz window QQ on the centre of the sensitive surface A, which is placed in focus of a telescope, or rather a little behind this focus, so that the light of the star may cover the whole of the selenium area.

The covering of the whole area A by the light is essential, for the following reason:—

The seat of the electromotive force is the surface of contact of the liquid and the selenium, the selenium receiving a positive and the liquid a negative charge. If, now, P is connected with one pole of an electrometer and P′ with the other, and if there is any portion of the selenium surface which is not exposed to the light (and consequently not the seat of an E.M.F.), this inert portion will act simply as a conductor conveying a portion of the positive charge to the wrong pole of the electrometer, and thus giving a diminished effect.

The truth of this is easily verified with any kind of photo-electric cell, *e.g.*, one formed of a sensitive tinfoil surface divided into two

portions which can be metallically joined together outside the cell or kept separate. If, while the portions are joined, one is exposed to, and the other screened from, incident light, the E.M.F. indicated is much less than it is when both are exposed, or when one alone is exposed while the other is disconnected from it. (A description of such tinfoil cell will be found in the 'Philosophical Magazine' and in the 'Proceedings of the Physical Society.')

This fact now enables us to see the importance of preventing the liquid from entering the glass tube AB, which contains the conducting wire P, for it is clear that, when the light is incident at A, the liquid which has crept into the tube round the aluminium wire will convey a portion of the negative charge imparted to the liquid in the cell to the wrong pole of the electrometer, and will thus diminish the effect of the light.

The capillary entrance of the liquid into the tube AB may, of course, be prevented by sealing into the tube a *platinum* instead of an *aluminium* wire, and coating the end of it with the selenium layer. But, unfortunately, platinum is not so good a base for the selenium as is aluminium, owing, almost certainly, to the fact that selenium enters into chemical composition with platinum, while it does not do so with aluminium, or with some other metals which, possibly, may yet be used.

The entrance of the liqnid could also be prevented by using a platinum wire instead of an aluminium one, and then coating the end of the platinum wire at A with a deposit of aluminium; but, although this is doubtless possible, success in the attempt has not yet been attained.

Air-tightness is another essential condition of the constancy of these photo-electric cells, for it is found that in cells which are not quite air-tight the resistance of the œnanthol increases very much after a few weeks, probably owing to the oxidation of the liquid by the air; and this great increase of resistance promotes sluggishness in the response of the cell to the action of light.

An examination of a seleno-aluminium cell with the various portions of the spectrum of lime-light shows that the cell is sensitive to all the rays from the end of the red, and below it, to beyond the violet, the maximum E.M.F. being produced in the yellow: but the magnitude of the E.M.F. does not vary very greatly until the violet is reached. In this respect the seleno-aluminium cell differs from all other photo-electric cells, for the sensitiveness of most of the latter is almost wholly confined to the blue. It may be mentioned, however, that a cell formed by immersing clean silver plates in a solution of eosine gives electromotive forces of opposite signs for the red and the blue rays.

The energy incident on a photo-electric cell has been found to be

proportional to the square of the electromotive force generated. If one candle held at a certain distance from the cell gives a difference, E, of potential between the poles P, P′, two candles close together will be found to give a difference $E\sqrt{2}$. Or, if a candle be tried at different distances from the cell, the difference of potential will be found to vary inversely as the distance.

Intrinsic Energies of Stars.

If I is the total amount of energy radiated into space in any time by a star at the distance r from the earth, the quantity received on any given surface on the earth will be proportional to I/r^2; and if E is the electromotive force which this generates in a given cell, we have

$$I/r^2 = kE^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1),$$

where k is some constant. Hence, if I′ is the intrinsic energy of another star at the distance r', and E′ the corresponding E.M.F.,

$$I'/r'^2 = kE'^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2),$$

from which we have

$$\frac{I}{I'} = \frac{E^2 r^2}{E'^2 r'^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3).$$

Hence, if the parallaxes of the two stars are known, say p and p' respectively, we have

$$\frac{I}{I'} = \left(\frac{Ep'}{E'p}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4).$$

When it is desired to compare the energy of a star with that of the sun, we must know the area of the sensitive layer, A, Fig. 1, of selenium in the cell. Let this be a, and let A be the area of the aperture of the telescope.

Then, since it is not desirable to concentrate on the selenium the amount of solar light which falls on the large area A, we must turn the cell to the sun without the aid of the telescope. Let E be the E.M.F. observed, S the intrinsic energy of the sun, and r the distance of the sun from the earth. Then

$$a\frac{S}{r^2} = kE^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5),$$

while, for any star whose distance is R, giving an E.M.F. equal to e,

$$A\frac{I}{R^2} = ke^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6).$$

$$\therefore \frac{I}{S} = \frac{a}{A}\left(\frac{eR}{Er}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots \quad (7).$$

As the electromotive force produced by the light of the sun falling directly on the cell is probably too large, it will be desirable to diminish its intensity by taking it through a small measured aperture and placing the cell at a known distance behind.

The Electrometer employed.

The instrument employed for measuring the electromotive forces generated by the light of different stars is a quadrant electrometer differing from the forms in ordinary use in having its quadrants made of aluminium, two of these being supported on brass pillars connected with the case of the electrometer and always earthed, while the other two are supported on pillars of melted quartz. The quadrant box is about 2 cm. high and 5 in diameter; the needle is of thin aluminium foil, cut into the peculiar shape figured in Clerk Maxwell's 'Electricity and Magnetism,' and is suspended by a quartz fibre about 9 cm. long. The needle and quadrants are surrounded by a thick metal case, and the instrument is both air-tight and induction-tight.

It had been intended to use with the electrometer an air condenser consisting chiefly of two gilt brass plates, each about 15 cm. in diameter, to multiply the potentials indicated by the electrometer; but at present there are difficulties in the way of its employment, and the measures made on this occasion were made by the electrometer alone.

Both instruments were constructed with the aid of the Government Grant administered by a Committee of the Royal Society and were made by Mr. Paul of Hatton Garden.

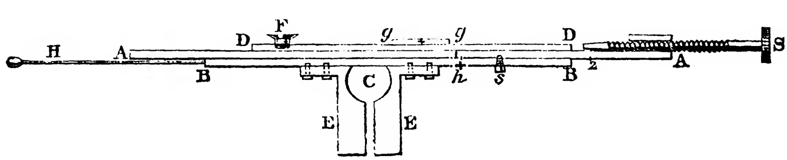
The Telescope.

This was Mr. Wilson's 2-feet reflector, which was at first used as a Cassegrain instrument, and subsequently as a Newtonian, the cell-carrier being in each case fixed to the telescope in place of the eye-piece.

The Cell-Carrier.

Fig. 3 represents the cell-carrier in plan.

Fig. 3.



A thin plate of brass AA with a circular hole of about ·75 cm. diameter in the centre of its vertical face (not represented in the figure) is fitted with a screw, S, at one end. This screw pushes forward another thin brass plate, DD, which moves backwards and forwards in a grooved space in the plate AA. The plate DD has likewise a hole in its centre and is moved in one direction by S and in the opposite direction by the finger applied to a screw F, attached to DD near one end. A small thin brass plate, *gg*, is attached to DD, and can move up and down (*i.e.*, at right angles to the plane of the figure) in a grooved space in DD by means of a screw which is not represented in the figure. This plate *gg* has also a hole in its centre over which is cemented a thin circular glass plate carrying crossed spider lines, represented in the figure by +. The point of intersection of these cross-lines is capable of being brought into any desired position by means of the horizontal motions of the plate DD and the vertical motions of *gg*.

To the face of AA opposite to that on which DD moves is attached a thin brass plate, BB, which moves in a grooved space in AA. Through BB passes a screw, *s*, which penetrates a short distance into a special groove in BB which is terminated at the points marked 1 and 2. These points are, therefore, stops to determine the extreme positions of the sliding plate BB on the fixed plate AA.

The plate BB has a circular hole of about ·75 cm. in diameter in its middle, and also another, *h*, a little to the side. Over *h* is cemented a thin plate of glass on which can be marked two cross-lines marked + in the figure, or a dot.

An ebonite block with a cylindrical hole, C, into which fits the cell represented in fig. 2 is screwed to BB just over the central hole in BB.

The plate BB is moved backwards and forwards by a projecting handle, H.

The fixed plate AA is screwed to a stout cylindrical tube about two inches long (not represented), and this tube fits on the telescope instead of the usual eye-piece. AA can be adjusted, if necessary, to various positions relative to this tube, *i.e.*, relative to the telescope.

To set the apparatus for a star, the procedure is this: move the plate BB (and with it of course the cell) by the handle H until it is stopped by the stop 2; move the intersection of the cross-lines on *gg* by means of the screw S and the screw which moves *gg* vertically until this point of intersection is exactly opposite the centre of the sensitive surface of the cell (which is, of course, visible through all the holes in the plates); bring back BB by means of H until it is stopped by the stop 1; the glass plate covering the hole *h* is now visible opposite *gg*—or rather through *h* we can see the intersection

of the cross-lines on *gg*; mark on the glass at *h* with a fine brush point a dot exactly opposite the intersection of the cross-lines of *gg*; remove *gg* out of the field of view by the vertical motion of the screw attached to it and to the plate DD—this being done in order that the light of the star may not have to pass through the glass plate on *gg*. This completes the adjustment.

To use the instrument with a star, keep BB stopped by the stop 1, so that the mark or dot at *h* is in position to receive the image of the star. Suppose, then, that by the adjustment of AA relatively to the telescope the image of the star falls exactly on this mark. Now by means of the handle H move BB until it is stopped by the stop 2. This brings the centre of the sensitive surface into the position occupied by the mark at *h*, *i.e.*, the image of the star is now falling on the sensitive surface of the cell.

When we desire to throw off the star, we can do so by moving BB with the handle H until it is stopped by the stop 1; but it is better to effect this by moving the telescope itself in declination, without going near the cell, until the star is out of the field, as indicated by the finder; in this latter way the cell suffers no disturbing effects of temperature, &c.

Connection of Cell with Electrometer.

One pole (the insensitive) of the cell was connected with earth by a wire attached to a gas-pipe, while the other (that of the sensitive surface) was attached to a fine uncovered copper wire, carefully insulated throughout, which passed down through a shellac plug in the floor of the observation room to the electrometer in the room below.

The readings of the electrometer deflections caused by the light of the stars were made in the lower room by Professor Fitzgerald, while Mr. Wilson and I attended to matters upstairs. But in this part of the work the services of my two colleagues were of very much greater use than mine.

The Observations.

Regulus was the first star taken, on the night of the 11th April, and only two observations of the deflection on the electrometer scale produced by its light were made before proceeding to an examination of Arcturus for comparison. It is thought desirable to show in tabular form a few of the results obtained. A Leclanché cell produced on the scale a deflection of 530 mm., the scale being about 7 feet from the electrometer.

Every photo-electric cell of the type previously described and of maximum sensitiveness has a certain native or disturbing E.M.F.,

Experiment.	Scale reading, star off cell.	Scale reading, star on cell.	Scale reading, star off cell.	Difference from mean.
1	150	146·5	151	4·0
2	151	146·0	150	4·5

which is always opposed to the E.M.F. generated by light. In this case it was represented by 11·2 mm.

The second column of this table contains the number on the scale at which the spot stood when the cell was in the dark, *i.e.*, when the only E.M.F. in it was its disturbing E.M.F.; the second column contains the number to which the spot moved when the light of the star was allowed to fall on the sensitive surface in the cell.

It will thus be seen that the E.M.F. due to Regulus in these two experiments was represented by the number 4·25, or about 4·25/530 of a Leclanché.

Arcturus when tried gave the following results, after a few preliminary observations (which were tried in the case of Regulus also, and which are rendered necessary after the disturbances caused in shifting the telescope, &c.) :—

Experiment.	Reading, star off.	Reading, star on.	Reading, star off.	Difference from mean.
1	135·5	128·0	135·5	7·5
2	135·5	Clouds	came	up.
3	145·0	138·0	143	6·0
4	143·0	Clouds	came	up.
5	136·0	137·0	Found star	off the wires.
6	139·0	132·5	139	6·5
7	139·0	130·0	135	7·0
8	135·0	127·0	134	7·5

These observations were somewhat irregular, because the sky was not quite clear during most of the observations, but was getting clearer as they proceeded.

The last was probably the best observation, and in that case Arcturus produced a voltage of about 0·02.

An experiment was made to try whether, if the cell were exposed to the sky in the neighbourhood of the star, but not to the star itself, any effect was produced, and a deflection of about 0·5 mm. in the direction *opposed* to that of the deflection caused by light was constantly observed.

If we take this effect into account, we have as the deflections due to

Regulus	4·75
Arcturus	8·00

Assuming now the latest determinations of the parallaxes of these stars to be

Regulus	0·093″
Arcturus	0·018″

we have from equation (4) the ratio of their respective intrinsic energies, I, I′, the result

$$I'/I = 75{\cdot}72,$$

showing that Arcturus radiates into space about $75\frac{3}{4}$ times as much energy as Regulus in a given time.

The telescope was next turned to the star η Boötis, with the result:—

Experiment.	Reading, star off.	Reading, star on.	Reading, star off.	Difference from mean.
1	133·5	133	133·5	0·5
2	133·5	133	133·5	0·5

If the radiation to the sky is added, the star's deflection amounts to 1 mm., *i.e.*, a voltage of 0·0028.

This observation is, however, recorded merely for the purpose of showing that a comparatively faint star is able to give an unmistakeable E.M.F.

The telescope was next turned on Saturn, whose image was so large that the ends of his rings were probably off the sensitive surface in the cell. The observation was:—

Experiment.	Reading, star off.	Reading, star on.	Reading, star off.	Difference from mean.
1	129	125·5	129	3·5
2	129	125·0	129	4·0
3	129	122·5	126	3·75

Between the second and third of these experiments the cell had been slightly disturbed, so that the last is not very satisfactory, although it gives the mean result.

The glare from the moon was now very distinctly apparent, and its effect seemed to be a deflection of about 0·5 mm., which must be deducted from Saturn's effect. This latter would, then, be represented by about 3·25 mm., or a voltage of 0·009.

The next observations were made on the night of Friday, the 12th, and on this night the atmosphere was very hazy, although many stars were visible. It is not necessary to enter into the details of observations on such a night; nevertheless, it may be interesting to see the effects which were observed.

For the following bodies the mean deflections were as tabulated:—

Jupiter	6·33 mm.
α Cygni	0·50 ,,
Vega	2·26 ,,
Arcturus..........	2·50 ,,
Regulus	1·10 ,,

A standard candle placed at a distance of 9 feet from the cell produced a deflection of 11 mm.

Nothing of a quantitative nature can be deduced from these results owing to the presence (and unequal distribution) of haze, the effect of which was to make Vega produce a deflection less than that of Arcturus.

On the night of the 14th the sky was clearer, and while Arcturus gave a very fairly constant deflection of 4·5 mm., Regulus gave 1·85 mm., ϵ Boötis 0·32 mm., α Coronæ 0·6 mm., and β Herculis something less than 0·2 mm.

The night of the 15th was, for a short time, much clearer, and during this time the following more reliable measures were made:—

Arcturus........	8·2 mm.	(mean of 4 observations)
Saturn..........	5·6 ,,	(,, 4 ,,)
Vega	11·5 ,,	(,, 2 ,,)
Candle at 9 feet..	10·0 ,,	
Leclanché cell ...	513·0 ,,	

It would be interesting to compare the intrinsic energies of Arcturus and Vega, but the parallax of Vega seems to be almost more uncertain than that of Arcturus. It is given in Young's 'Astronomy' as 0·16, while Miss Clerke gives Elkin's value as "0·034?" If the first of these is taken, with the value 0·018 for Arcturus, equation (4) gives the intrinsic energy of Arcturus equal to 38·2 times that of Vega; but if the second is taken, this number becomes only 1·8.

Comparison with the Photometric Method.

In the ordinary method of comparison of "magnitudes," if B and B′ are the brightnesses of two stars whose magnitudes are m and m', respectively, we have, by definition,

$$\log \frac{B}{B'} = \tfrac{4}{10}(m'-m) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5).$$

Now, taking Arcturus and Regulus as of the magnitudes 0·3 and m', respectively, and the electromotive forces of their lights as 8 and 4·75 (determination of April 11, previously cited), we have

$$\log \left(\frac{8}{4{\cdot}75}\right)^2 = \tfrac{4}{10}(m'-0{\cdot}3),$$

$$\therefore m' = 1{\cdot}43.$$

The magnitude of Regulus, as a matter of fact, is variously cited as from 1·42 to 1·7; thus the amount of correspondence between the photo-electric and photometric methods is seen.

Concluding Remarks.

Among the few bright stars which we found available was Procyon, and even this star offered an opportunity for observation during a very limited time, owing to mechanical hindrances in the Observatory. The stars in the Great Bear shone brilliantly, and, under favourable circumstances, their light could have been easily measured. The constellation was, however, so nearly vertical, that the aperture in the roof of the Observatory was not sufficiently wide to suit the aperture of the telescope, and hence no observation of any of these stars was attempted.

On one night observations of Procyon and Regulus were taken. The readings were much smaller than had been anticipated from the great sensitiveness of the cell and electrometer. When these observations were completed, the cell was exposed to a candle at 9 feet, and the effect was so small, that it was evident that some accidental circumstance was intervening. The cell was, therefore, taken down from the telescope and examined, with the result that we found an opaque movable portion of the cell holder covering a portion of the sensitive surface in the cell. This was at once removed, and then the candle, Arcturus, and Vega gave the large deflections quoted in the observations of the 15th. It was, however, then too late to get Procyon again. But the observations which had been made with this star and Regulus, while the partial obstruction of the cell remained, gave the mean of their deflections as

Regulus	1·27 mm.
Procyon	1·90 „

Now, although the accidental obstruction renders this comparison unsatisfactory, it is remarkable that these numbers accord fairly well with the "magnitudes" of the two stars, as given by Miss Clerke ('System of the Stars,' Appendix, Table III). Thus, the "magnitude" of Regulus is given as 1·4, and that of Procyon as 0·5.

Now, in equation (5), if we put $B/B' = (190/127)^2$, and assume the magnitude of Regulus = 1·4, while that of Procyon = m, we have

$$5 \log \tfrac{190}{127} = 1{\cdot}4 - m,$$

$$\therefore m = 0{\cdot}53,$$

which is a rather close coincidence.

On the same data equation (4) gives the result

Intrinsic energy of Regulus = 3·6 × intrinsic energy of Procyon.

It is hoped that these measurements will be resumed about the end of next September, at Daramona, by the same observers; and, in the meantime, some improvements will be effected in the cell-holder which will facilitate observation. An endeavour will also be made to improve the cell itself in the directions indicated at the beginning of this Report.

The experiments prove conclusively that there is little difficulty in obtaining fairly accurate measurements of the light of stars of the first and second "magnitudes," even without the employment of a multiplying condenser or a larger telescope. A telescope with an aperture of 5 or 6 feet would certainly annex a very great number of stars to the list.

It is right to put on record the fact that the first photo-electric observations of planets and stars were made by Mr. Monck, in Dublin, in the year 1892, in conjunction with Professor Fitzgerald. My cells were at that time much less sensitive than the present ones; and, for reasons set forth in this paper, their sensitiveness fell off after about six hours. The liquid in those cells was acetone, and the aluminium on which the selenium was deposited was not insulated from the liquid. Nevertheless, Mr. Monck and Professor Fitzgerald were able to observe electromotive forces due to the light of Venus, Jupiter, and, I think, Mars. Mr. Monck's telescope is a refractor of 9 ins. aperture, so that large results were not to be expected. These observers were not quite certain whether Vega and Capella produced measurable effects or not; but their observations were much interfered with by draughts of air, and other things, in their observatory.

FIG. 2.